



Development of a Longitudinal Density Monitor for Storage Rings

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Longitudinal Density Monitor

- LBL funded (FY2002-03) effort for:
 - Instrument design and engineering
 - Prototype building
 - Experimental runs at the ALS





All-in-One Tool

- Online measurement of **bunch length** and **shape**
- **Bunch current** – including nominally unfilled RF buckets (“ghost bunches”)
- **Synchronous bunch position**
- **Fast**: the results shown were accumulated in seconds/minutes
- **Very wide dynamic range** (10^4)





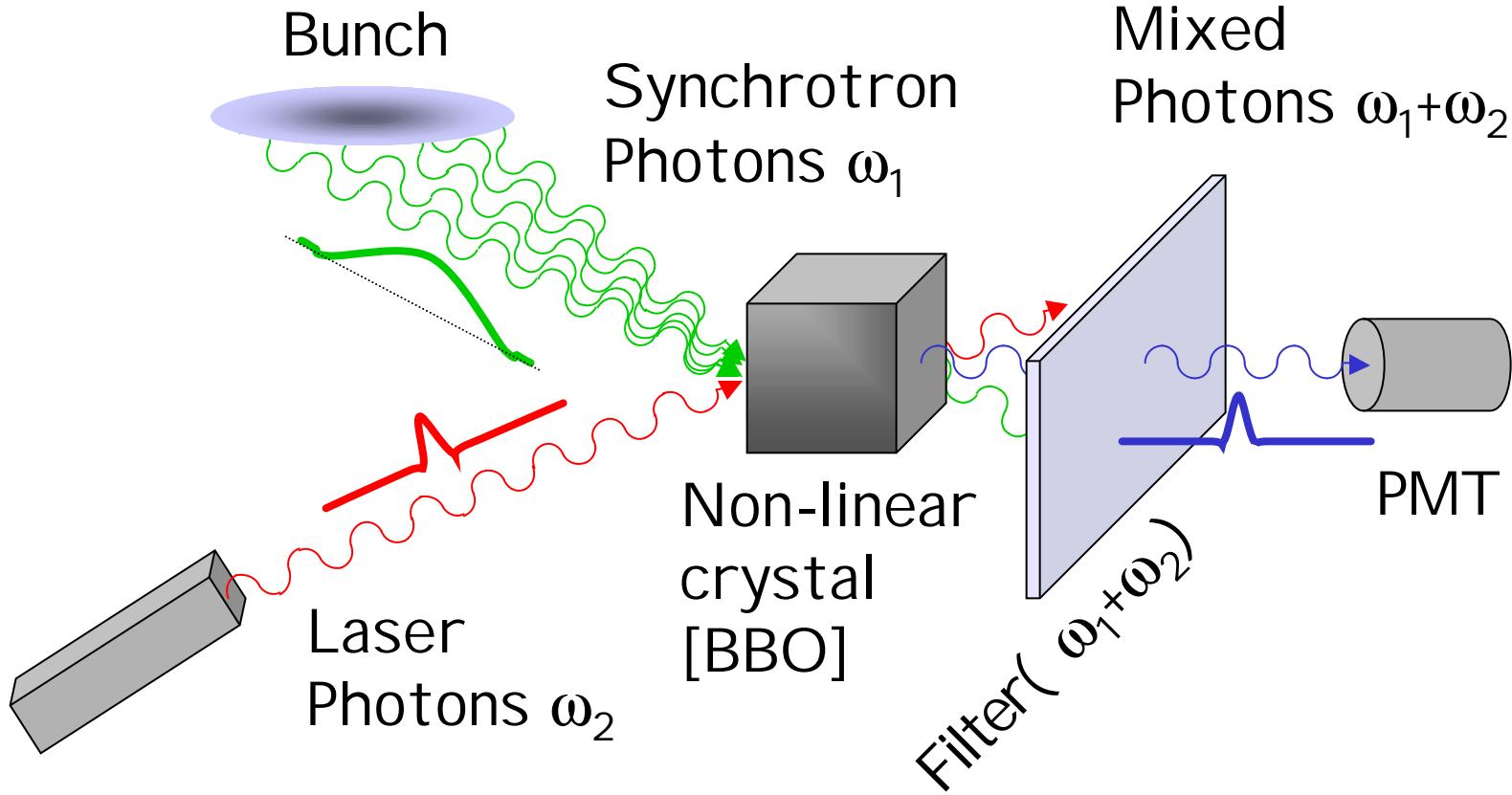
Summary

- **Longitudinal Density Monitor overview**
 - *what it does, how it does it*
- **The hardware**
- **Experimental runs at the ALS**
- **LHC specifications**
- **Future developments**



Concept

$\omega_1 + \omega_2 = \text{visible wavelength}$



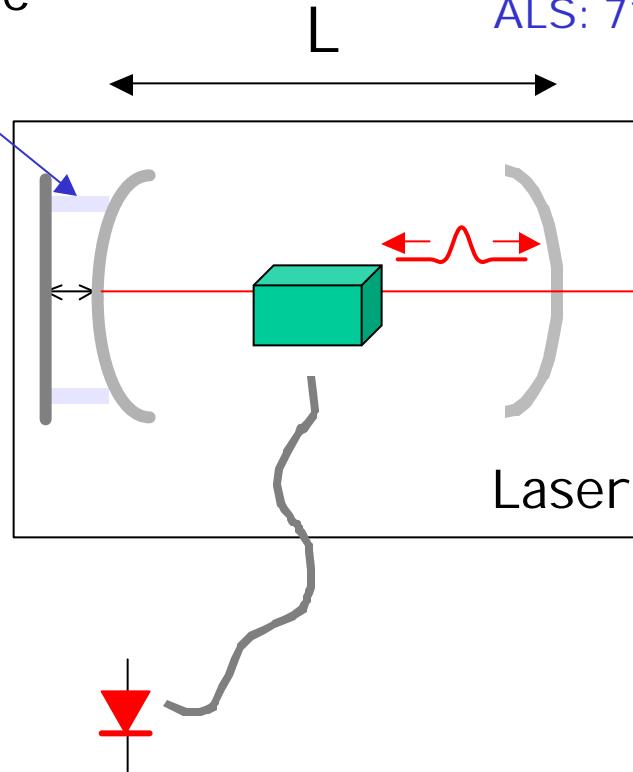
laser pulse length << bunch length

Scanning the Bunch

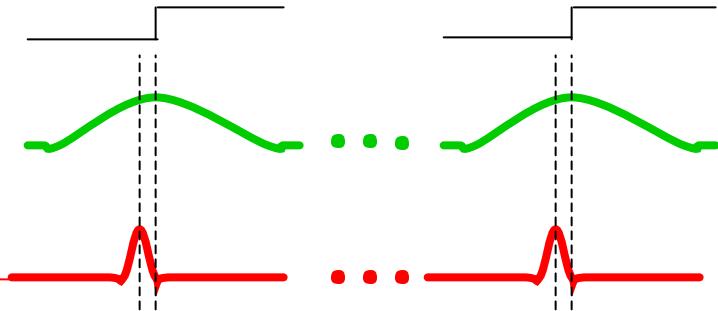


Piezo-ceramic
positioner

ALS: 10 Hz



LHC: 40 MHz
ALS: 71 MHz



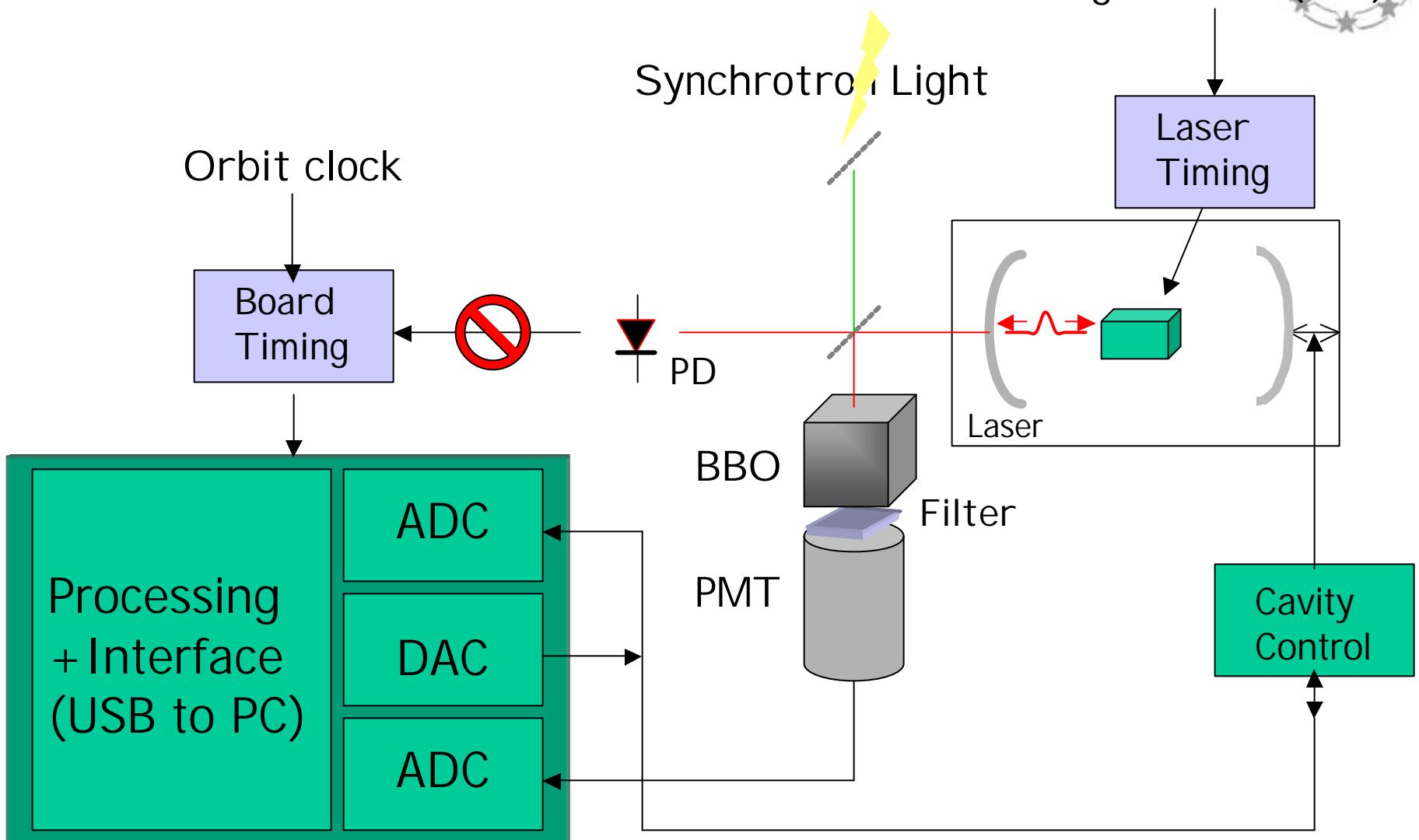
$C/2L = 40$ (or 71) MHz
Adjust ϕ by changing
path length (phase
modulation)

100-200 mW diode-pumped laser

ALS: 50 fs, LHC: 50 ps (10 W)

LHC: 22 bins (std. mode)
ALS: 32 bins

Schematic (timing)





LDM pros and cons

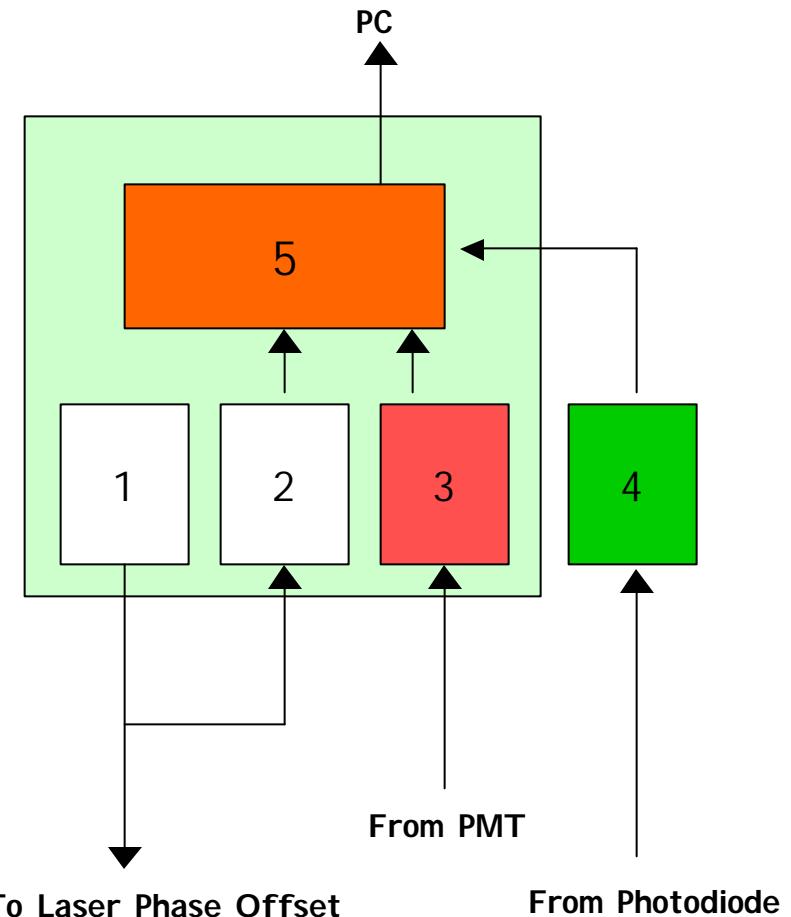
- Fast sampling rate (laser cavity frequency)
- High dynamic range
- High time resolution (laser pulse length)
- Not limited to optical wavelengths
- Requires multi-turn sampling
- Requires synchrotron light



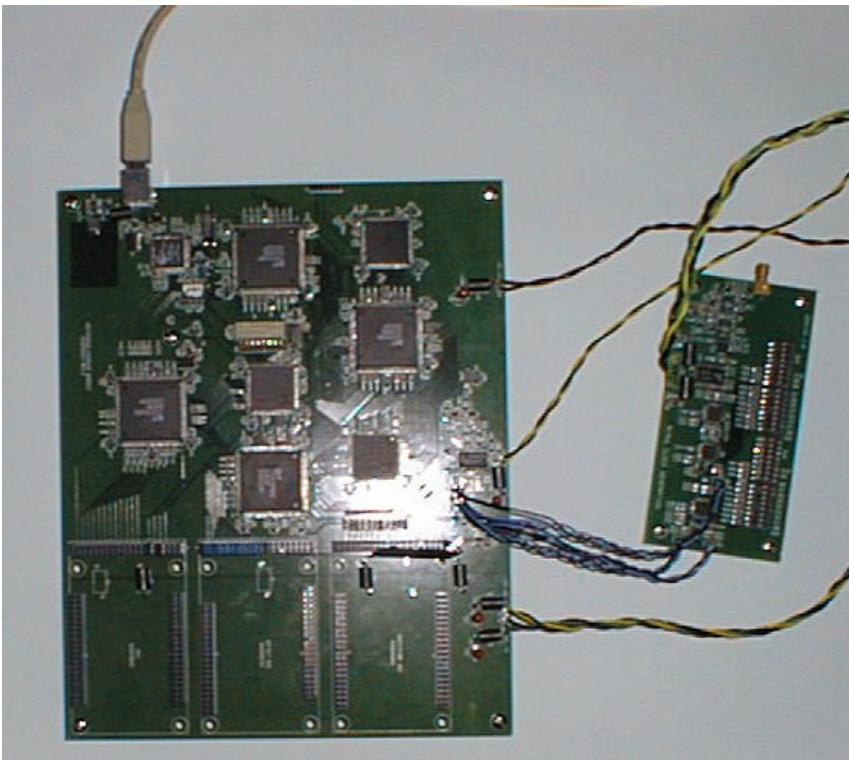


LDM - Current Situation

- Architecture – Different Boards
 - #1 : Phase modulation Generator
 - #2 : Phase Information Digitization
 - #3 : PMT pulse digitization
 - #4 : Delay generators/timing
 - #5 : Digital Backend (Storage and USB)



Electronics - I.

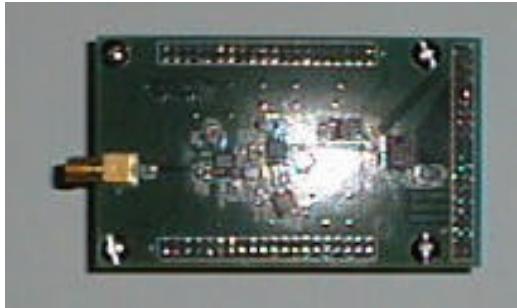


Mother Board with 71MHz clock board

USB Control and histogram/average
is fully operational

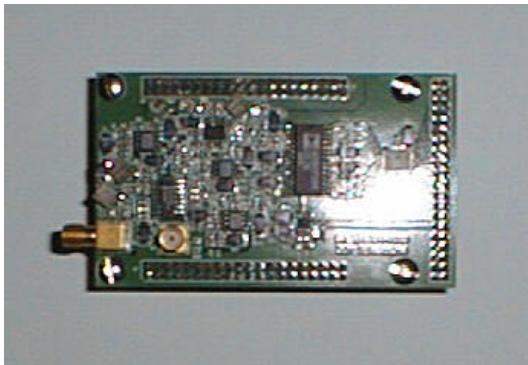
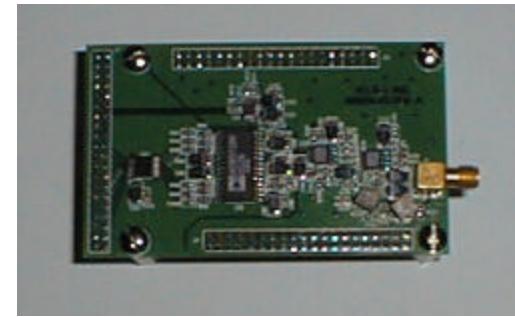


Electronics - II.



DAC Analog board for
laser phase offset
modulation

Actual Laser phase
offset digitization board



Track and Hold board with self
trigger for PMT pulse detection
(only one bit is used in **single photon**
counting mode)



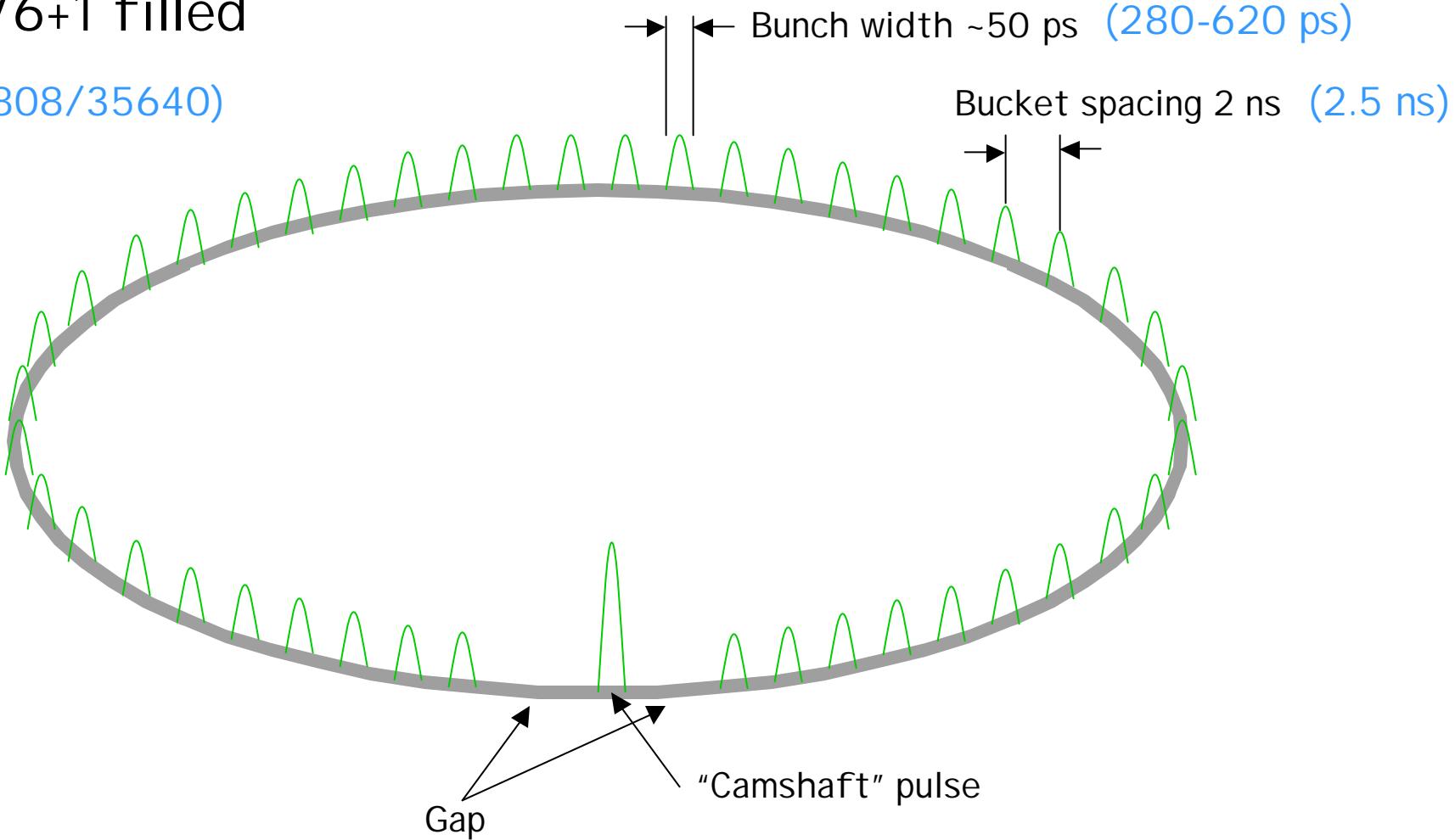
Tests at the ALS

(LHC parameters)

328 RF buckets

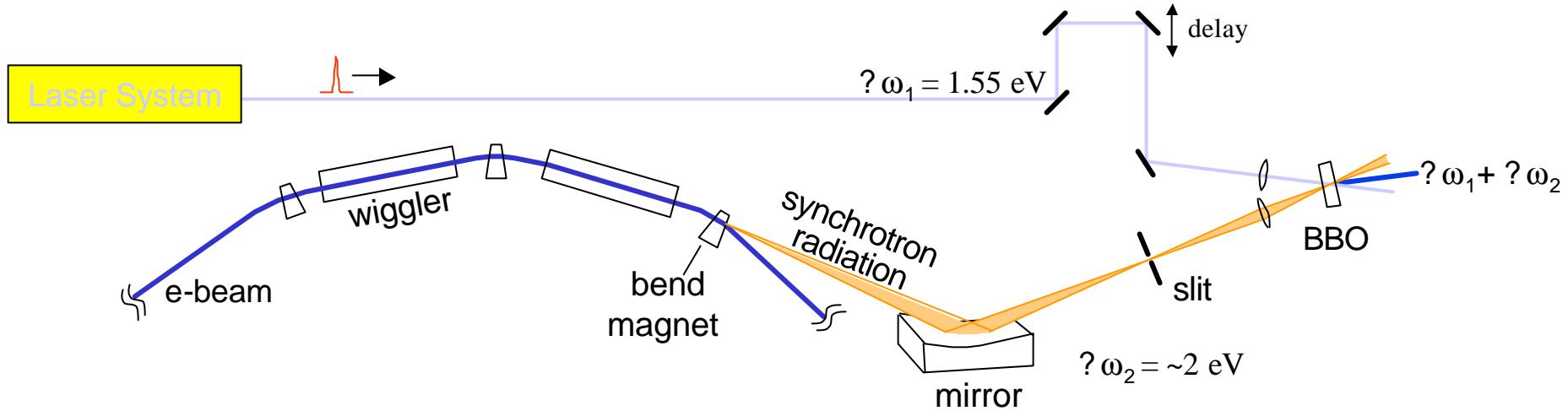
276+1 filled

(2808/35640)





Optical layout at the ALS





Experimental setup

- In Beamline 5.3.1 using existing fs laser
- Laser repetition frequency is 71 MHz (1/7 ALS frequency)
- Scan bunches in groups of 7, then shift 1 bunch
(0, 7, 14...; 1, 8, 15...; ... ; 6, 13, 20...)

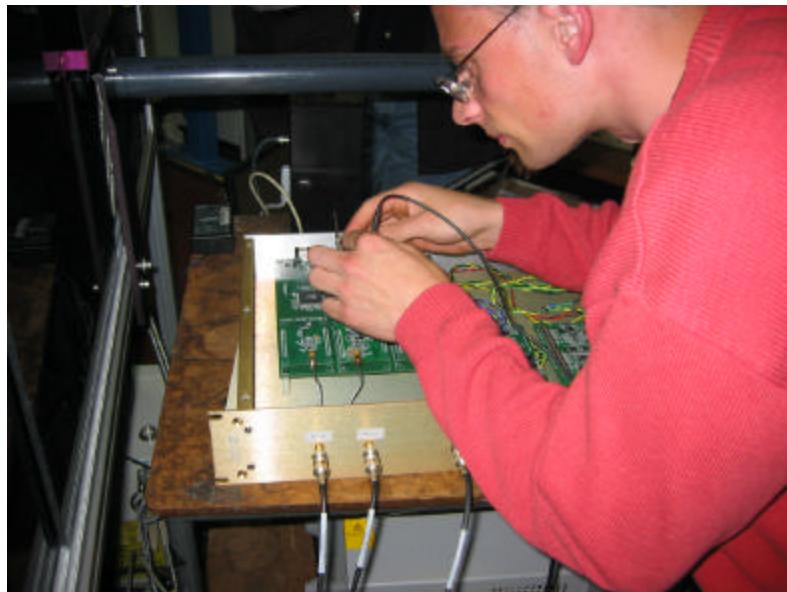
Electronics, DAQ + Software

- Histograms the signal from each bunch
- Drives mirror with programmable displacement
- Profiles the mirror displacement (for bin position in time)

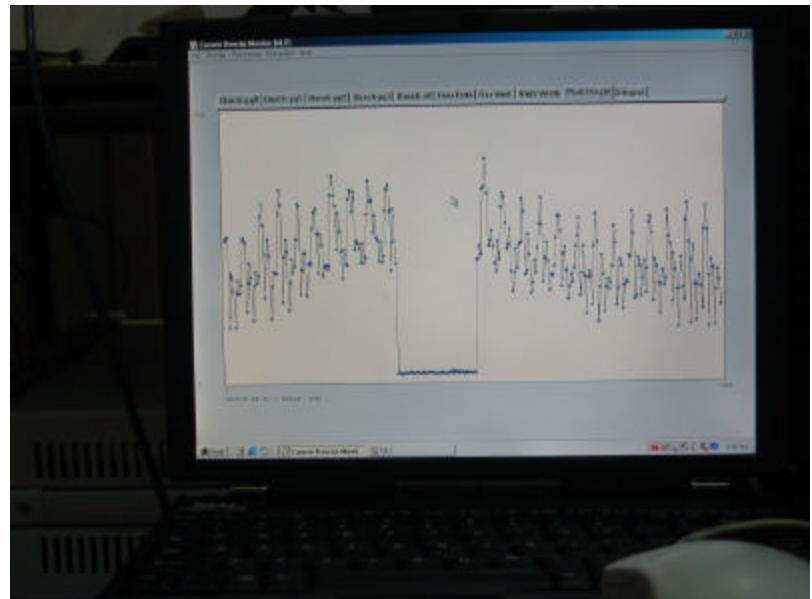




Experimental Setup



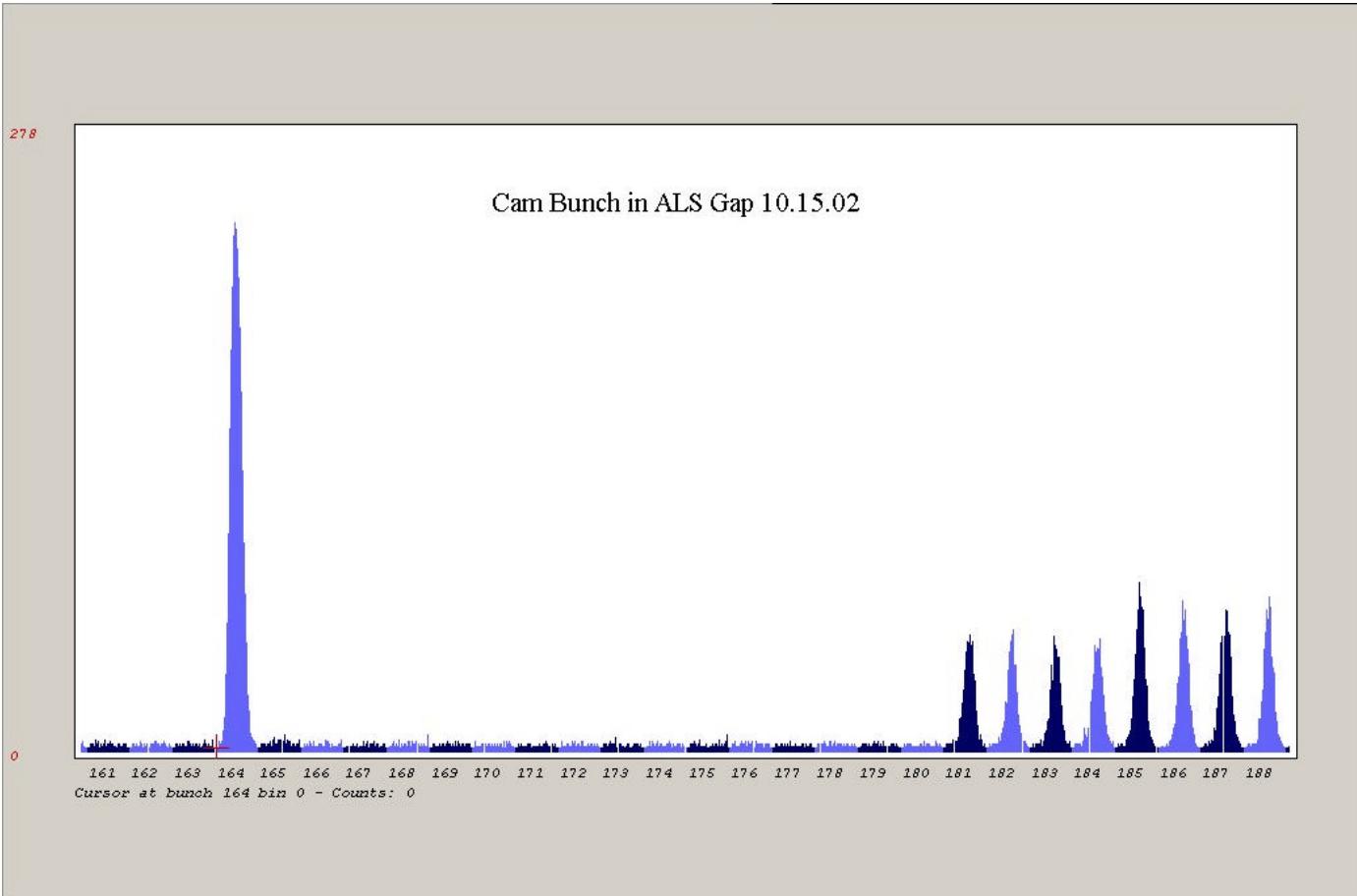
Electronics Setup



First data (Peak Height distribution)



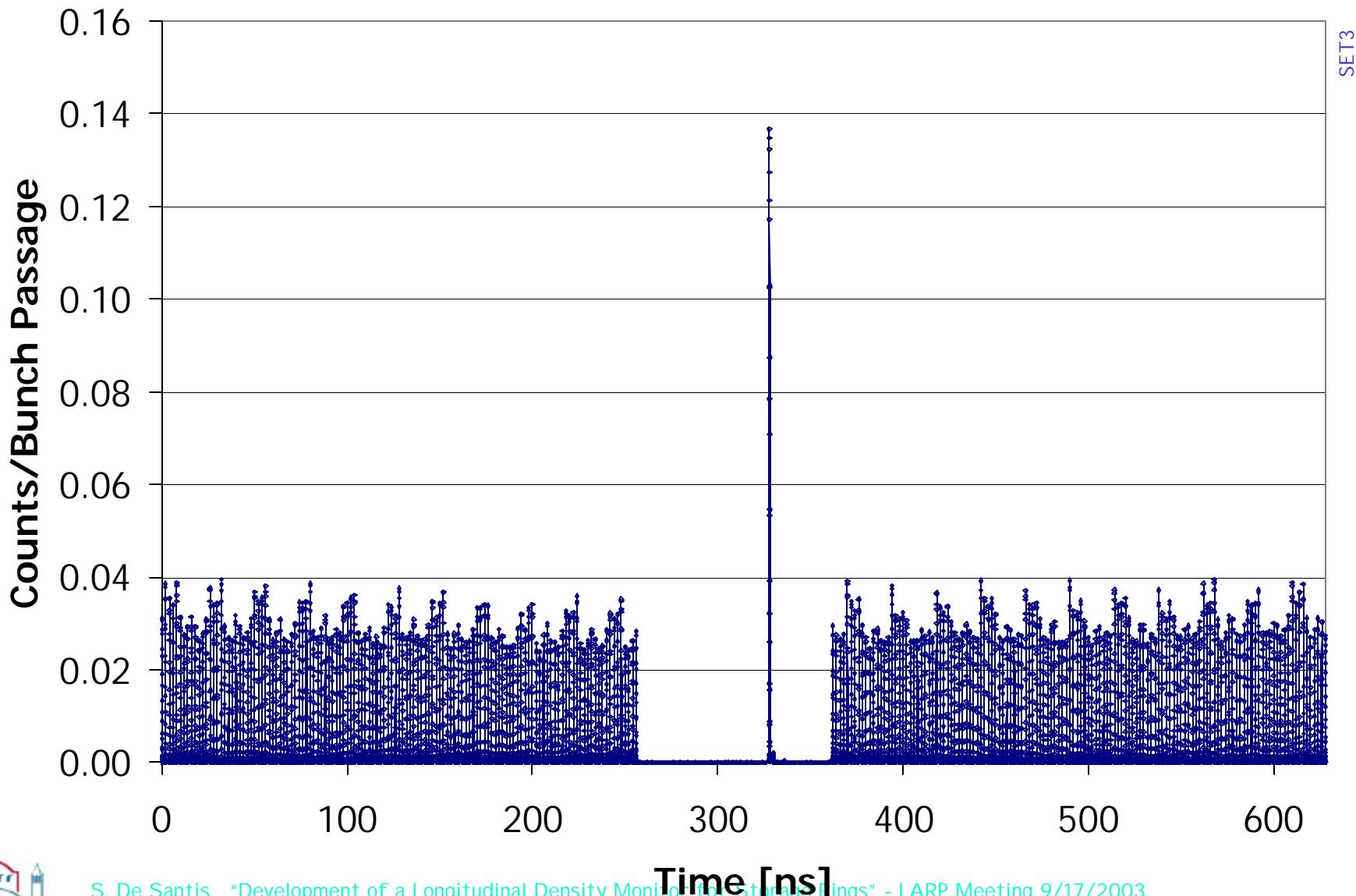
Online Results



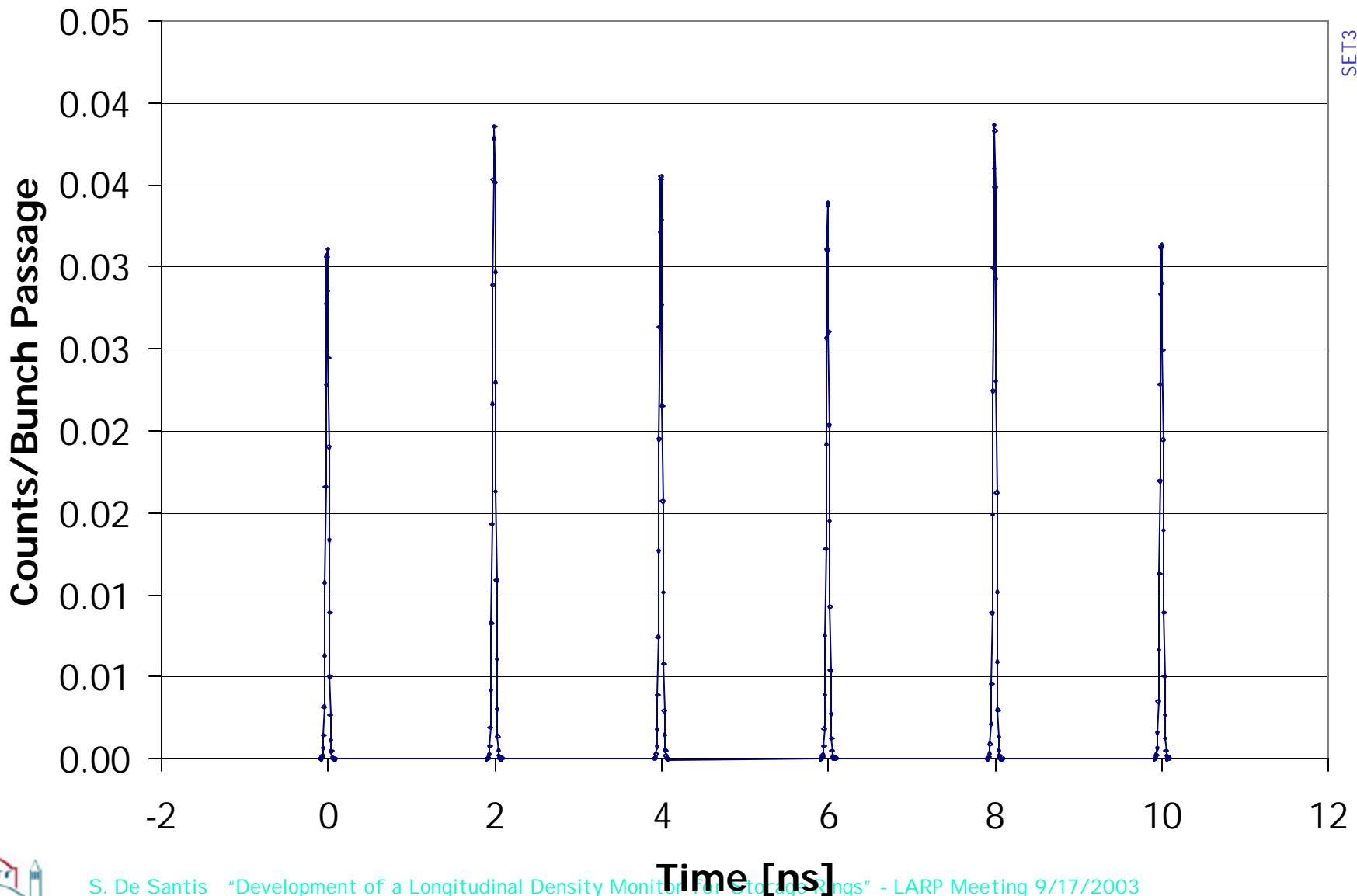
**Camshaft
followed by a
gap and then the
standard
bunches.**



ALS Bunch Profile in Time

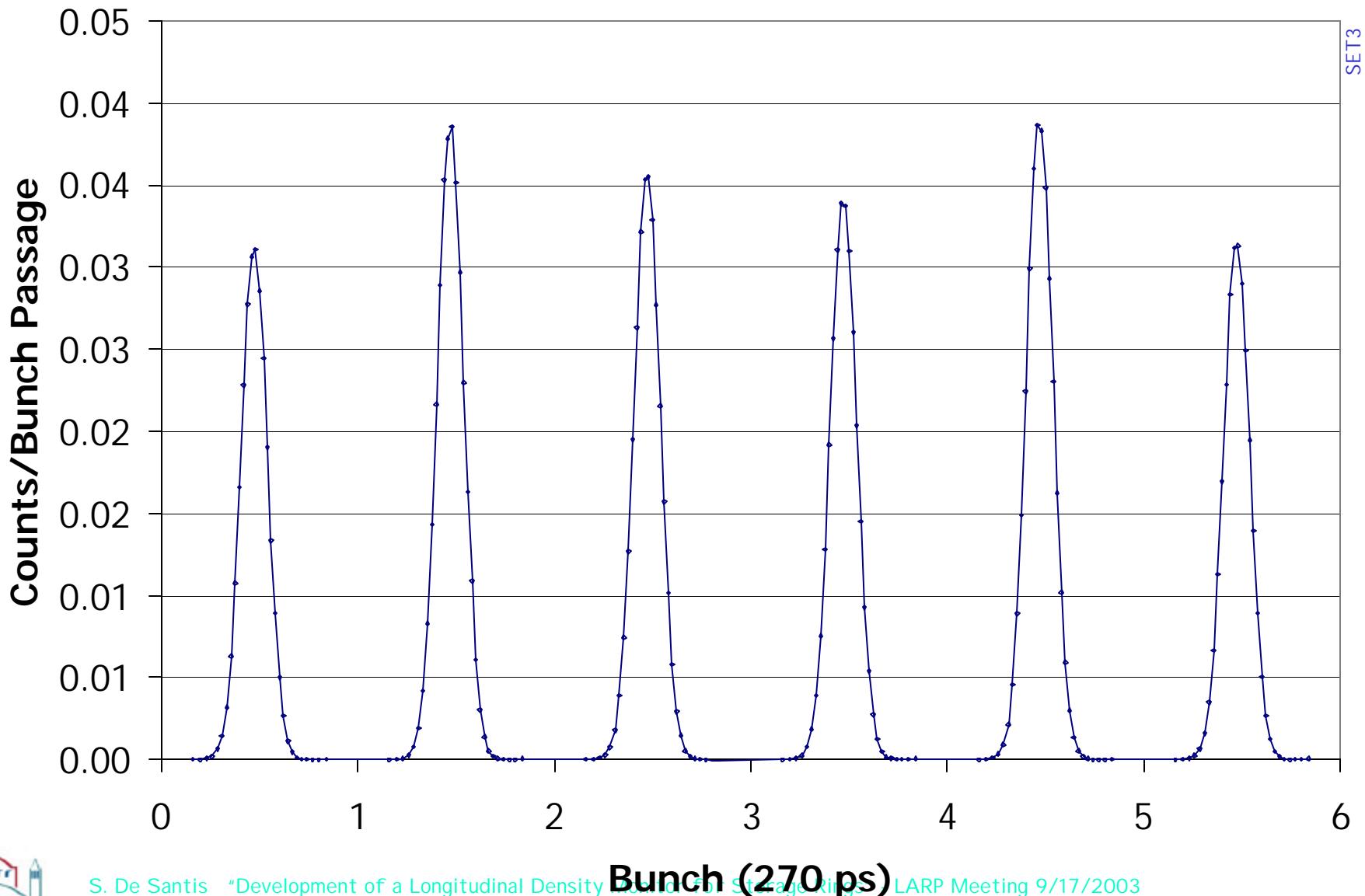


Zoom in...



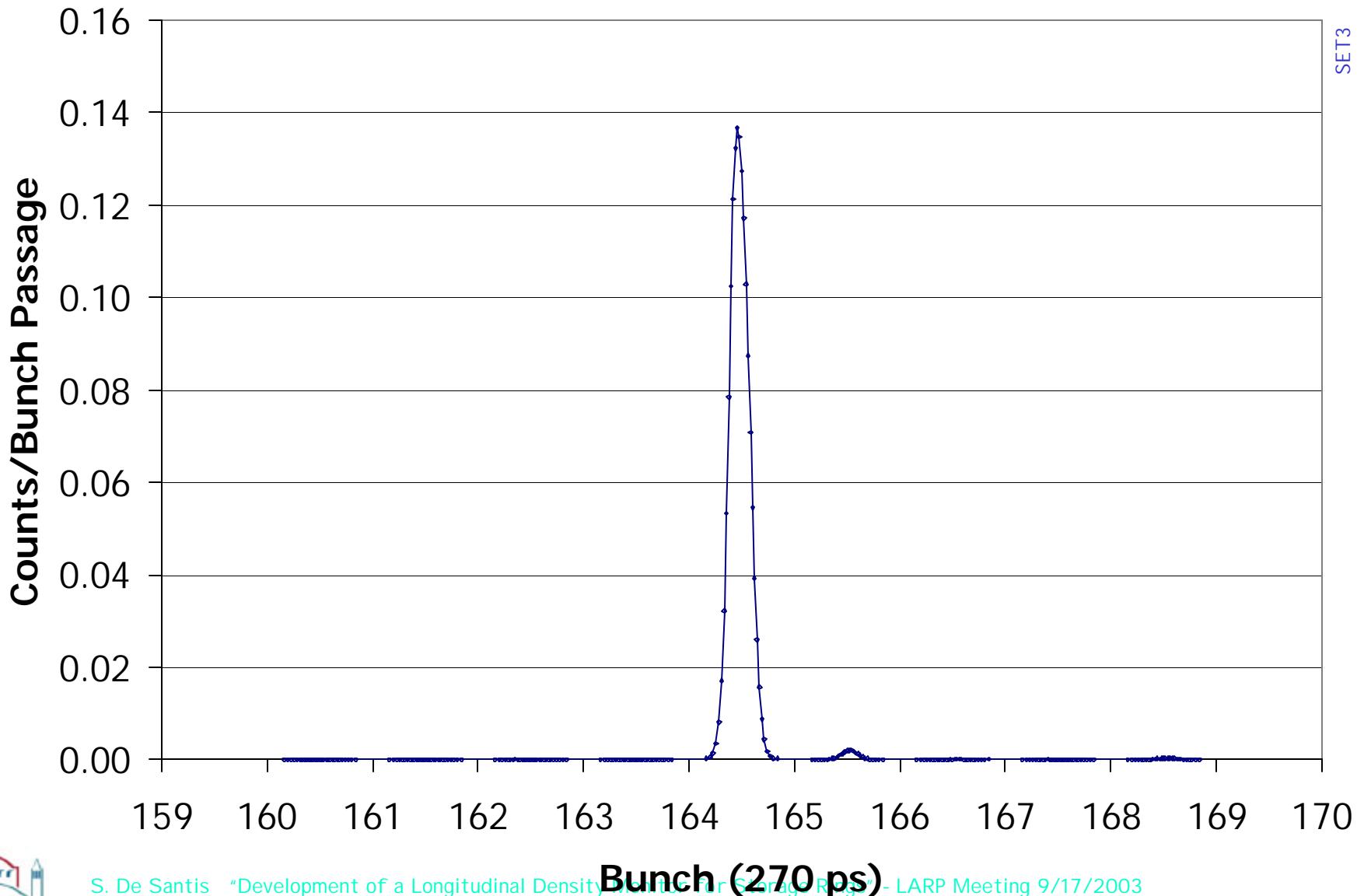


Compress Scale...



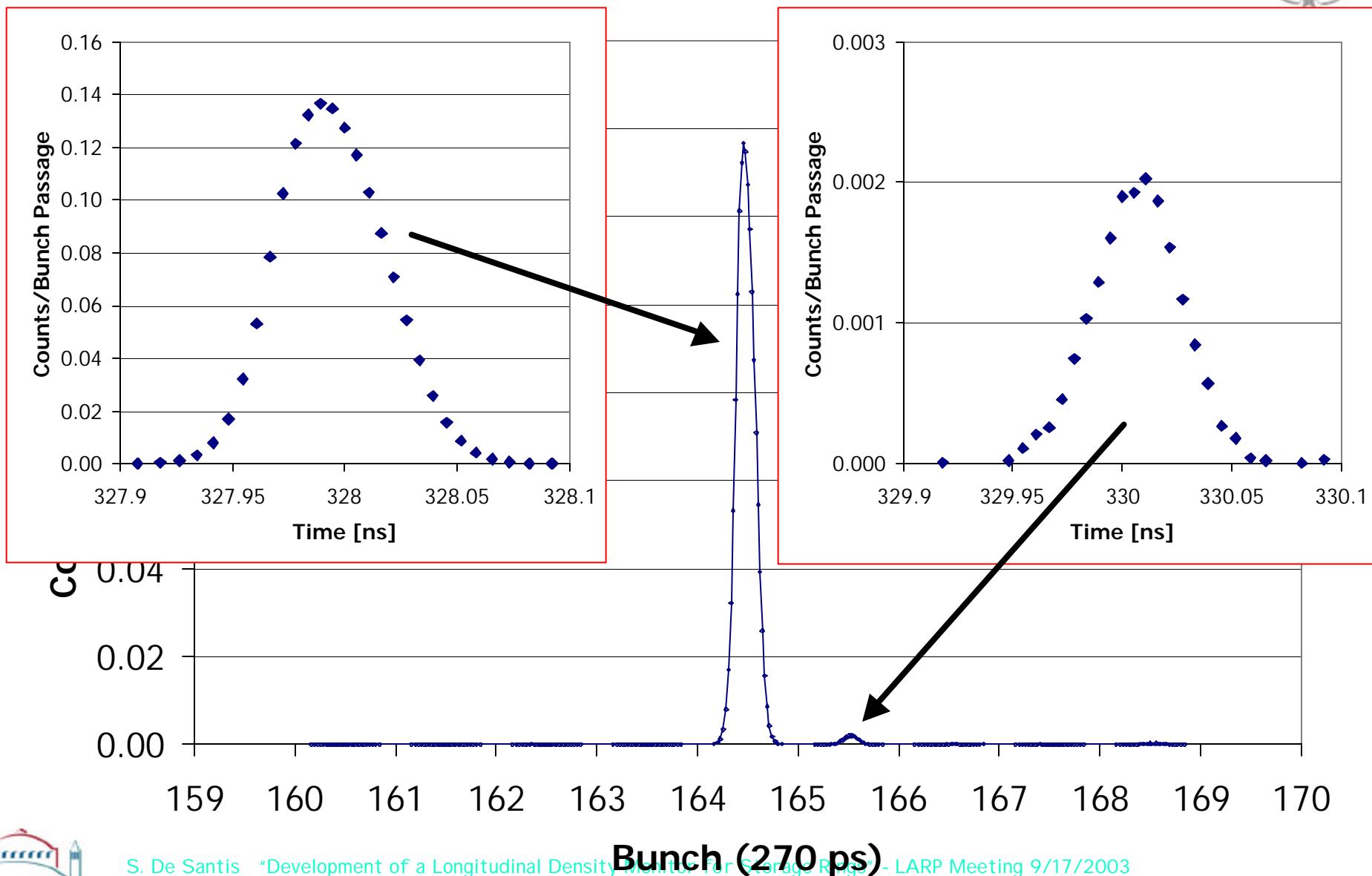


Large dynamic range





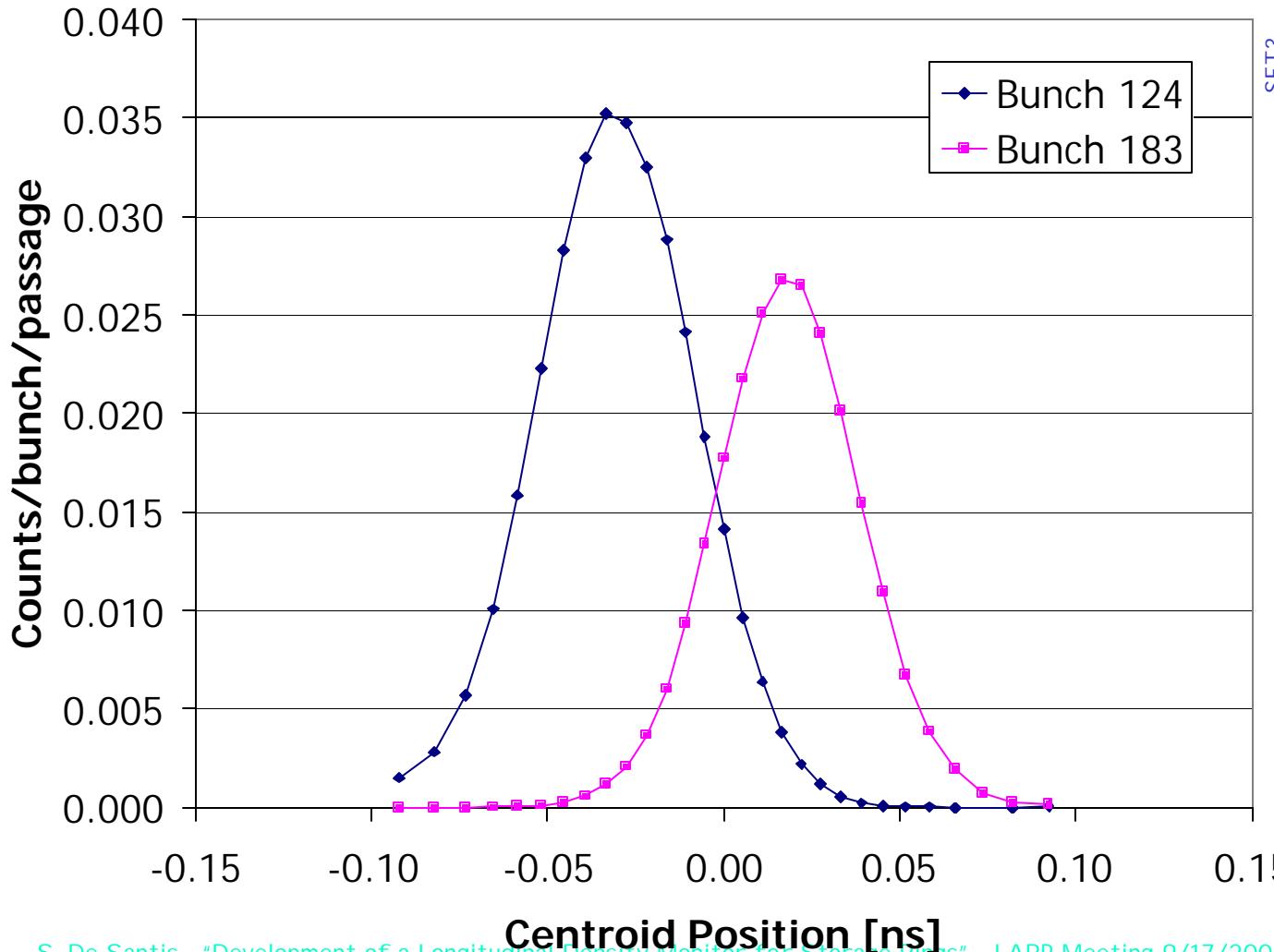
Details





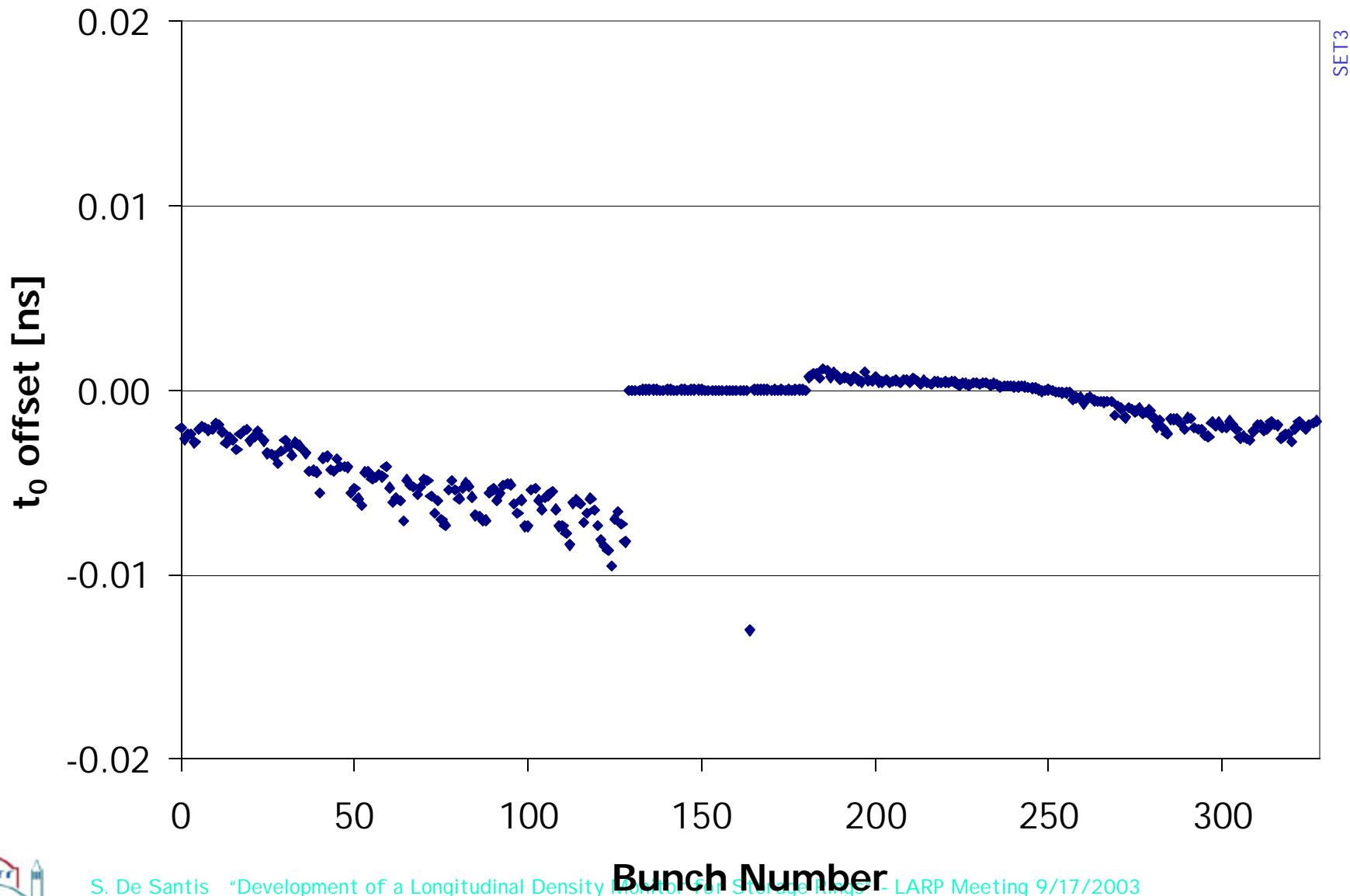
Synchronous Phase Transients

Bunch centroid phase



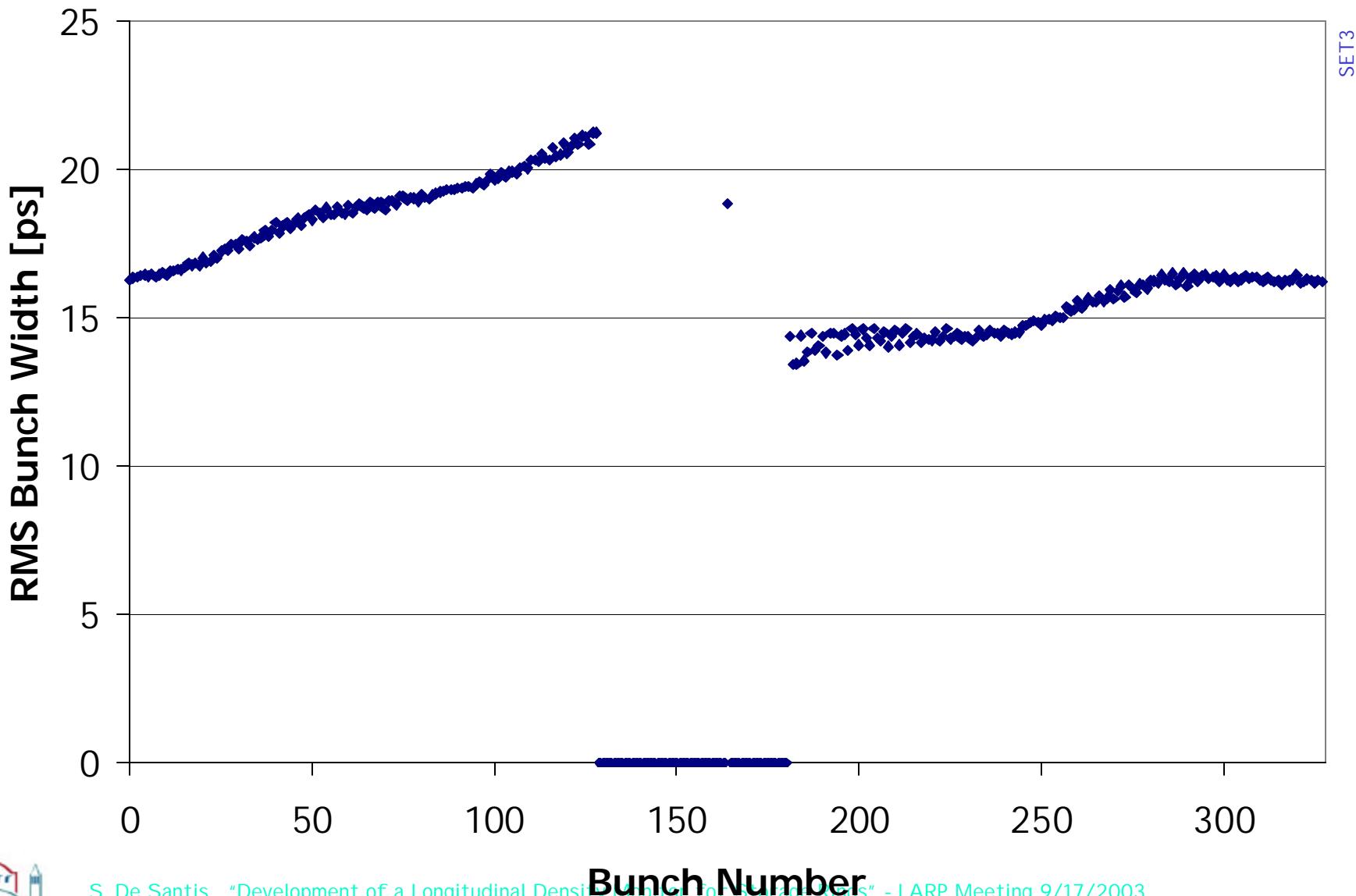


Synchronous Phase Transients





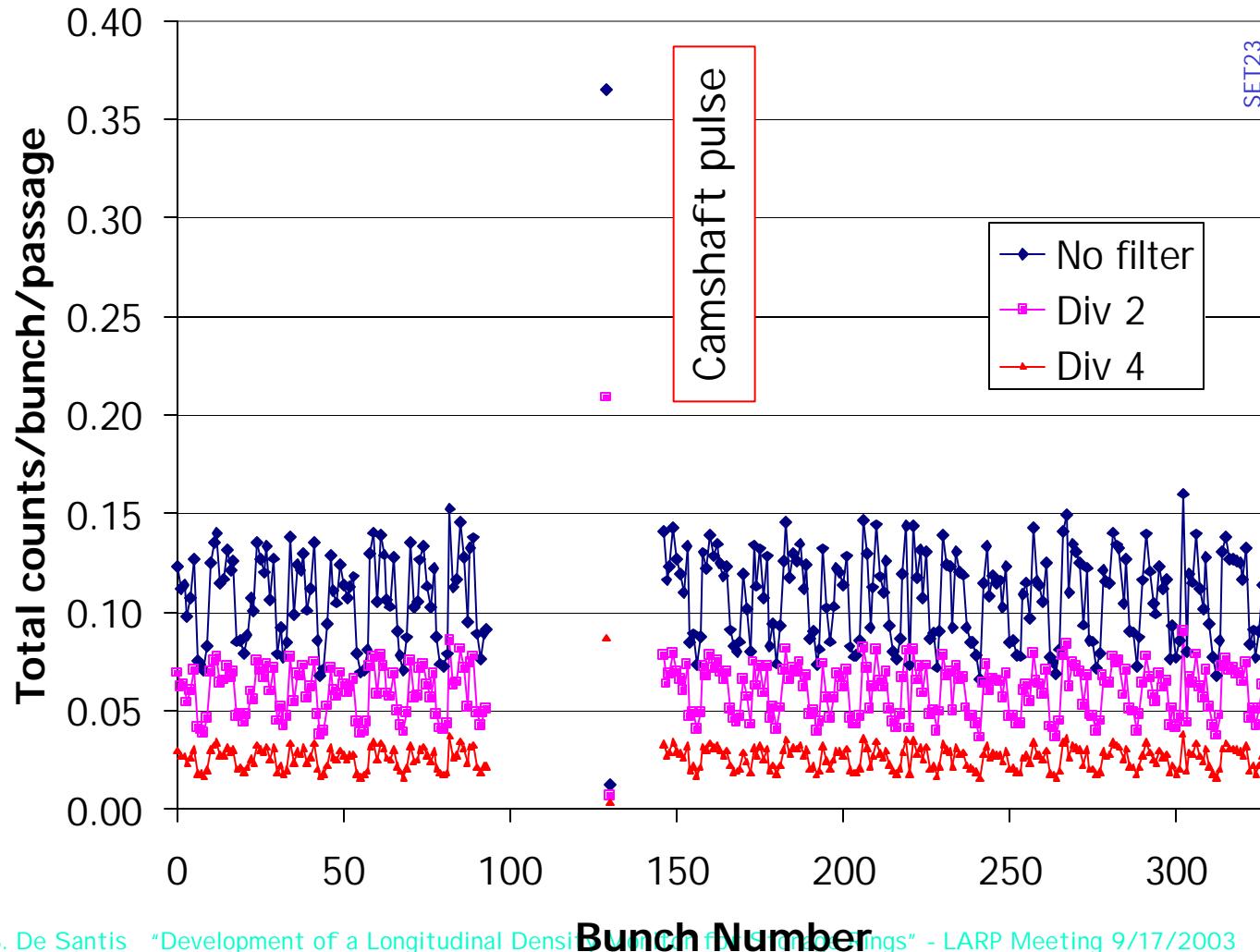
Bunch Length



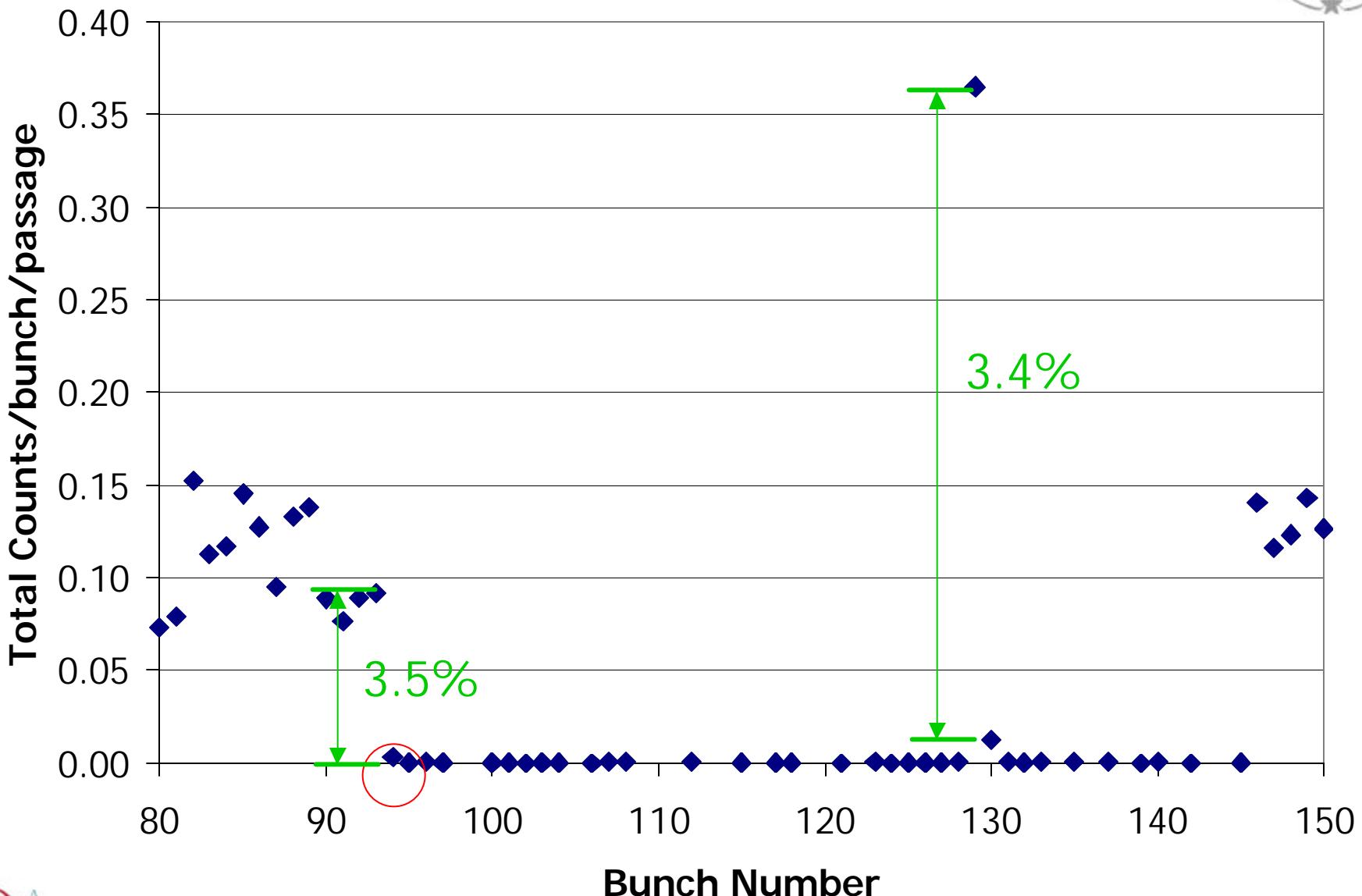


Linearity

3 runs - same fill conditions a filters in front of PMT

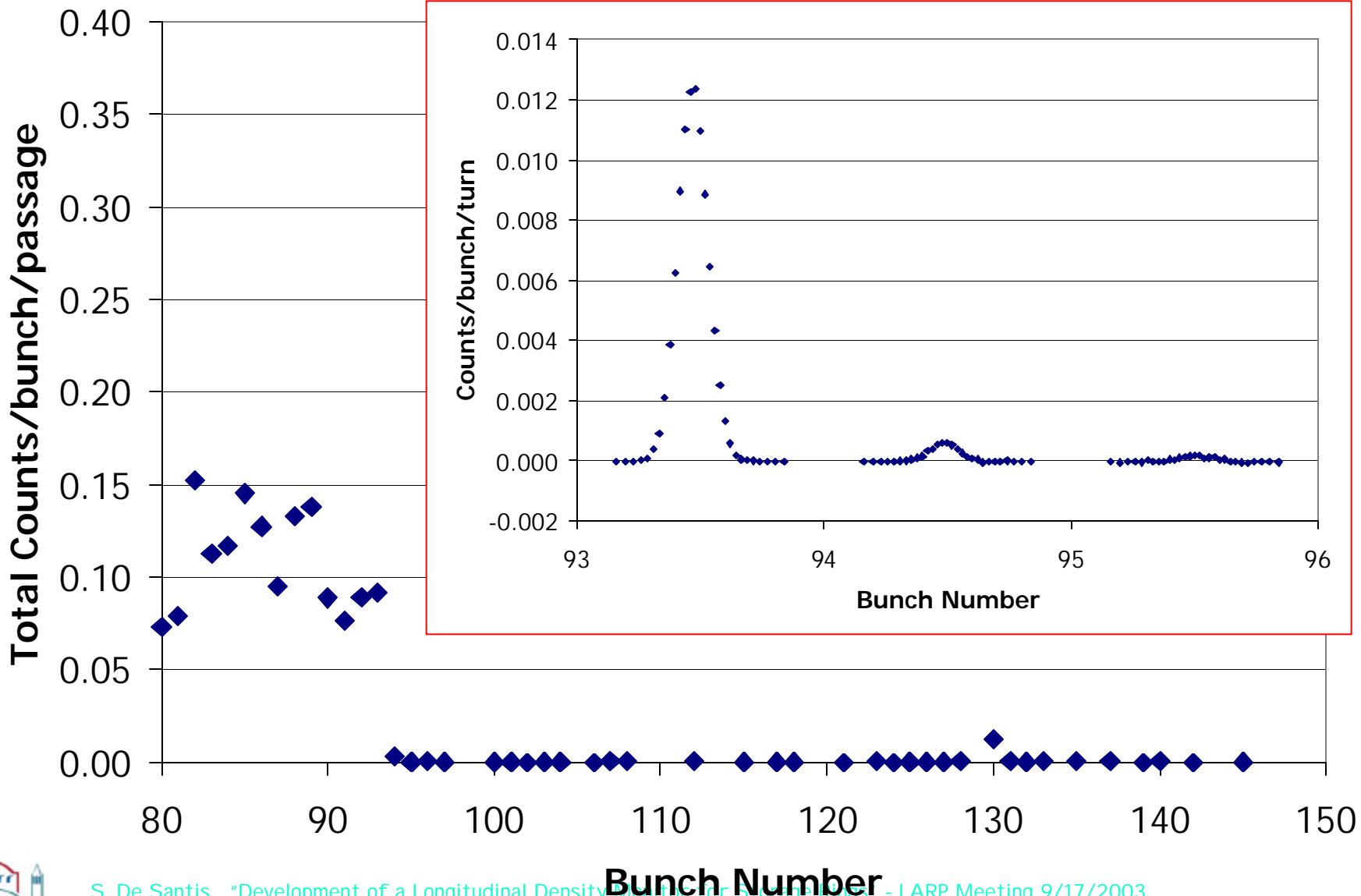


Dynamic Range



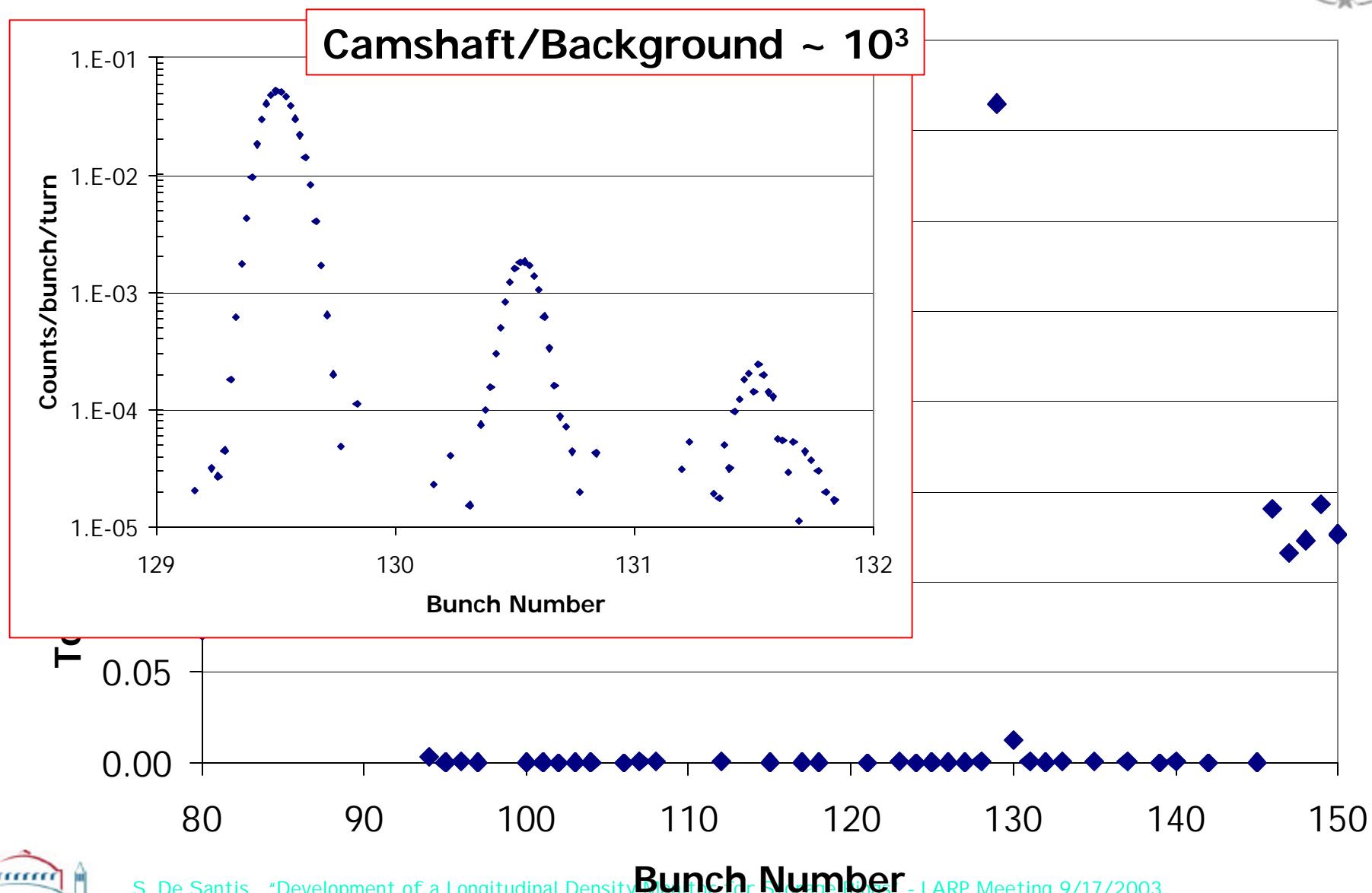


Zoom - I.





Zoom - II.





A Longitudinal Monitor for LHC

- 450 GeV - 7 TeV
- Untrapped beam fraction
- Protons in the abort gap
- Longitudinal bunch tails
- “Ghost bunch” population
- Etc.

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LHC Project Document No.
LHC-B-ES-0005.00 rev 2.0

CDM Dev / Group or Supplier/Collaborator Document No.

AB/BDE

CDMC Document No.

328145

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Functional Specification

HIGH SENSITIVITY MEASUREMENT OF THE LONGITUDINAL DISTRIBUTION OF THE LHC BEAMS

Abstract

The present specification provides the functional requirements of a monitor that will measure the longitudinal density distribution of the LHC beams with a wide dynamic range of more than 10^5 . This monitor is particularly suited to measure the tails of the bunches, to detect ghost bunches or a debunched fraction of the beam. It can be used to monitor the dump gap and ensure it does not become filled with beam. Data related to the beam core distribution: centre of gravity, edges, length, shape, will also be measured.

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LHC Applications of LDM

- Bunch core measurement (std. mode)
- Tails and “ghost bunches” (HS mode)
 - 10 W laser @ 1064 nm
 - Laser pulse period: 25 ns
 - Laser pulse length: 50 ps
 - LHC length: 88.9 μ s
 - Photons/bunch/turn: 10's (10^2 gain @ 450 nm) at full current





Bunch core measurement

- Measure bunch population at $\pm 2\sigma$ with 1% accuracy in a time short compared to the synchrotron period (~ 42 ms @ 7 TeV)
 - 22 bins required (50 ps \times 22 $\sim \pm 2\sigma$).
 - Time required to map the core once: 22 turns ~ 2 ms
 - Mirror specifications - R&D required.
 - Expected population: $2 \cdot 10^8$ - $2 \cdot 10^6$ p/ps.
 - Accuracy: 0.5-5.5%



Tails and “ghost bunches” measurement



- Measure bunch populations as small as $2 \cdot 10^4$ p/ps all around the ring (causing background in experiments) with ~50% accuracy.
 - Entire ring is mapped in 50 ps slices. Minimum number of turns: 500 (3556 slices/turn).
 - At 7 TeV, $(2 \pm 0.8) \cdot 10^4$ p/ps give 3.2 ± 1.8 counts in a 50 ps slice.
 - 1000 turns (< 100 ms) are required for the 50% accuracy as per specs.

LDM is the ideal instrument...





Future developments

- Use a standard data acquisition board from National Instruments, running LabView/C++.
- Clocking on storage ring orbit clock.
- Design optimization for LHC operations (40 MHz, proportional mode)
- Engineering of laser system and optical layout.



DAQ PCI 6534 National Instruments



- Standard DAQ Board
- Function Library Labview, C/C++ compatible
- Quad 8-bit I/O board, DMA transfer rates up to 20MHz (8, 16 or 32-bit)





Conclusions

- The LDM works !
- No major physics issues to be solved

Still required:

- Board redesign for reliability improvement
- Integration of laser system
- Optimization for LHC operations
- Additional funding

